Rough Surface Effects on Microwave Propagation over the Sea

Kenneth D. Anderson
SPAWARSYSCEN San Diego 2858
49170 Propagation Path
San Diego, CA 92152-7385
Phone: 619-553-1420 fax: 619-553-1417 email: kenn@spawar.navy.mil

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LONG TERM GOALS

The long-terms goals of the research are to understand the effects of marine boundary layer atmospheric mean and turbulence structures on the propagation of microwave signals over the ocean. For wind speeds greater than 10 m s^{-1}, it has been hypothesized that ocean surface waves distort the vertical refractivity profile leading to reduced microwave signal levels. Previous at-sea experiments have shown resonant effects of waves on the momentum flux and turbulence at wind-wave and swell scales. Current research focuses on wave effects on the scalars, temperature and humidity, that affect propagation.

OBJECTIVES

The objective is to obtain accurate mean temperature and humidity profiles over the ocean together with the surface fluxes of momentum, sensible heat, and latent heat. From these mean profiles establish the form of the scalar temperature and humidity profile functions and the resulting vertical refractivity profile. With sea surface elevation measurements and data from three sets of microwave transmitters at two heights, determine the significant factors (e.g., wind speed, significant wave height, wave age) affecting errors in predicting microwave signal strength from in situ meteorological measurements.

APPROACH

The approach is to perform a surface-layer experiment off of the Hawaiian Island of Oahu from the Research Platform Floating Instrument Platform (R/P FLIP). This experiment is called the Rough Evaporation Duct (RED) experiment. R/P FLIP hosted the primary instrumentation suite. The University of California, Irvine, (UCI) provided a vertical array of mean and fast response meteorological sensors (pressure, temperature, humidity, wind speed and direction) and a set of 1D sea surface elevation wave staffs. The Space and Naval Warfare Systems Center, San Diego (SSC SD) provided three sets of microwave transmitters at two heights (4 and 12 m asl), an infrared source, and aerosol particle counters. The Netherlands Physics and Electronics Laboratory (FEL/TNO) provided additional aerosol sensors and a scanning lidar. The Scripps Institution of Oceanography provided optical bubble sensors and an acoustic Doppler profiler. SSC SD established two land sites, one providing a 10 km electrooptical (EO) path and the other a 25.7 km microwave path. The Defense Research Establishment, Valcartier (Canada) provided a mean meteorological buoy, located mid way between R/P FLIP and the microwave receiver site. The Naval Postgraduate School (NPS) provided a

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14. ABSTRACT
The long-terms goals of the research are to understand the effects of marine boundary layer atmospheric mean and turbulence structures on the propagation of microwave signals over the ocean. For wind speeds greater than 10 m s-1, it has been hypothesized that ocean surface waves distort the vertical refractivity profile leading to reduced microwave signal levels. Previous at-sea experiments have shown resonant effects of waves on the momentum flux and turbulence at wind-wave and swell scales. Current research focuses on wave effects on the scalars, temperature and humidity, that affect propagation.

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mean and flux meteorological buoy that was located mid way between R/P FLIP and the EO receiver site. The CIRPAS Twin Otter aircraft also participated in RED.

WORK COMPLETED

A mission plan was executed for the RED experiment, 20 August to 18 September 2001. In February 2002, we held a first-look data-analysis workshop at Scripps Institution of Oceanography, La Jolla, CA, where we had 17 presentations covering all of the major aspects of the RED experiment. In February 2003, we held the second data-analysis workshop at the University of California, Irvine. This workshop immediately followed a special session on the RED experiment that was held during the 83rd Annual Meeting of the American Meteorological Society. The Rough Surface Effects on Microwave Propagation over the Sea project is complete at the end of FY 03.

RESULTS

Figure 1 shows the excellent agreement between modeled results, derived from in situ meteorology, and the measured signal strength (shown as propagation loss) for the X-band (9600 MHz) transmitters. The data (black dots) show that the evaporation duct (the vertical refractive profile) enhances the received signal levels by two to four orders of magnitude (100 to 10000) times the levels expected in a standard or normal atmosphere, which is shown as the dashed line labeled *troposcatter*. The mean error is –0.17 dB for the high-sited antenna and 4.27 dB for the low-sited antenna.

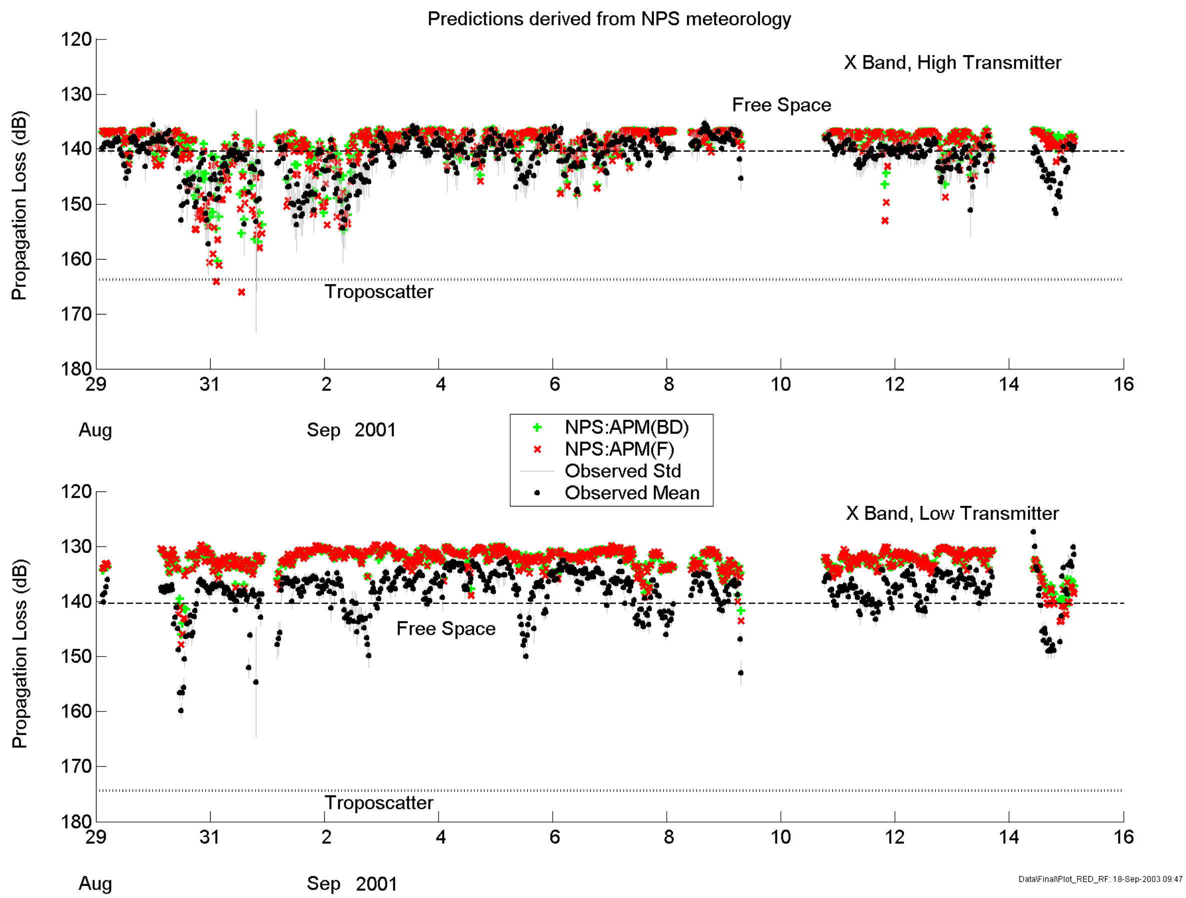

Figure 1. A comparison of predicted (red and green symbols) to measured signal levels at X-band (9600 MHz).

During the RED experiment, we did not get the high winds and high evaporation duct heights that we had anticipated. There was only one Eastern Pacific tropical cyclone that developed but it had minimal impact on the sea-state in Hawaii. However, comparison of 5 minute averaged observed-to-modeled propagation data for all 6 sets of transmitters are very good. In the generation of the modeled propagation data we used meteorological and surface inputs from the NPS buoy, which was located approximately 5 km westward (downwind) from R/P FLIP, and inputs derived from the UCI vertical array on R/P FLIP. Both of these data sets were used to drive the NPS "bulk model" that generated the refractive profiles needed by the Advanced Propagation Model (APM) to generate the modeled propagation data. The comparisons of observed-to-modeled propagation data are statistically better using meteorological inputs from the UCI array than using inputs from the NPS buoy. In addition, the NPS bulk model was modified to use both the standard Businger-Dyer profile functions of T and Q and a new form of the functions suggested by C. Friehe that were derived from UCI vertical array sensors during the RED experiment. Statistically, there is a slight improvement in the comparisons of modeled-to-observed propagation data using the new profile functions. However, additional work is needed to confirm the new profile functions and to understand their effects on microwave propagation over the sea.

IMPACT/APPLICATIONS

The impact of this research is the improvement of the basic understanding of temperature and humidity fluctuation and mean profiles in the atmospheric surface layer over the ocean. These scalars affect the vertical refractivity profile and therefore strongly affect microwave signal transmission over the sea. These results are readily incorporated into propagation models, such as APM. In addition, the data obtained will aid our understanding of wind-wave interaction.

TRANSITIONS

This work directly supports the ONR sponsored SSC SD Advanced Propagation Model (APM). APM Version 1.3.1 was transitioned into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 155, which has produced the Advanced Refractive Effects Prediction System (AREPS).

RELATED PROJECTS

This project is closely related to the ONR sponsored Coastal Boundary Layer Air-Sea Transfer project.

SUMMARY

The highlights of the RED experiment are:

- RED RF data analysis confirms that Monin-Obukhov Similarity Theory combined with a high-fidelity propagation model is a very good predictor of RF propagation in a homogeneous unstable marine boundary layer.
- RF, EO, and meteorological data collected during RED provide a high-quality benchmark data set that will be useful for validation of new models (*e.g.*, a periodic refractivity profile in both range and height).
- RED confirmed observations made during the 1996 MBL experiment that height variations in scalars (air temperature, humidity, etc.) are related to sea waves and supports Miles' critical layer theory.
- RED provided the first direct evidence that the specific humidity profile function over the sea is not equivalent to the heat profile function (results from CBLAST may confirm this observation).

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